

Chapter 4

Amplitude Modulator and Demodulator Circuits

Topics Covered

- 4-1: Basic Principles of Amplitude Modulation
- 4-2: Amplitude Modulators
- 4-3: Amplitude Demodulators
- 4-4: Balanced Modulators
- 4-5: SSB Circuits

4-1: Basic Principles of Amplitude Modulation

- Modulator circuits cause carrier amplitude to be varied in accordance with modulating signals. Circuits produce AM, DSB, and SSB transmission methods.

- The basic equation for an AM signal is

$$v_{AM} = V_c \sin 2\pi f_c t + (V_m \sin 2\pi f_m t)(\sin 2\pi f_c t)$$

- The first term is the sine wave carrier
- The second term is the product of the sine wave carrier and modulating signals.

4-1: Basic Principles of Amplitude Modulation

AM in the Time Domain

- Amplitude modulation voltage is produced by a circuit that can multiply the carrier by the modulating signal and then add the carrier.
- If a circuit's gain is a function of $1 + m \sin 2\pi f_m t$, the expression for the AM signal is

$$v_{AM} = A(v_c)$$

Where A is the gain or attenuation factor.

4-1: Basic Principles of Amplitude Modulation

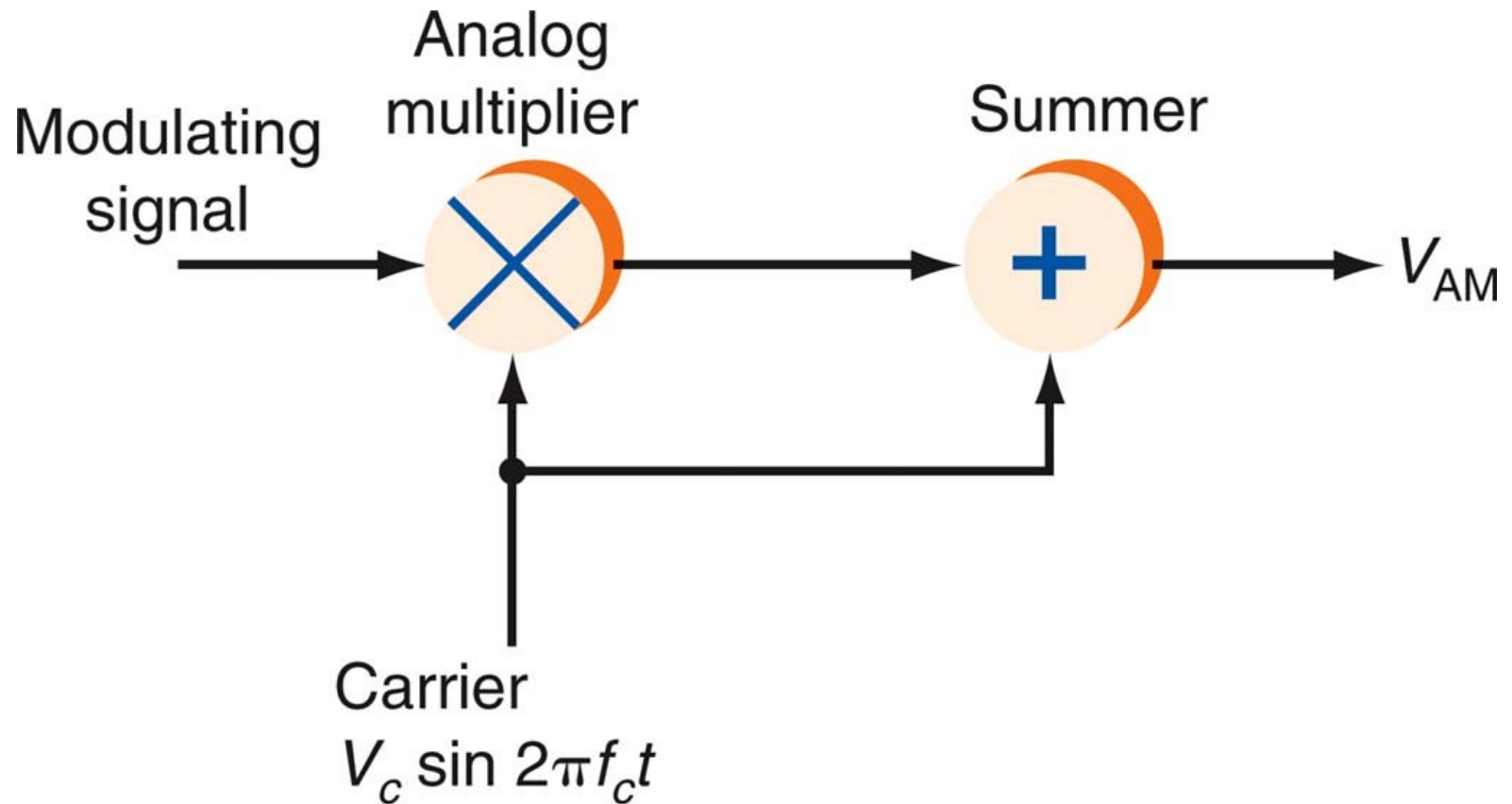


Figure 4-1 Block diagram of a circuit to produce AM.

4-1: Basic Principles of Amplitude Modulation

AM in the Frequency Domain

- The product of the carrier and modulating signal can be generated by applying both signals to a nonlinear component such as a diode.
- A **square-law function** is one that varies in proportion to the square of the input signals. A diode gives a good approximation of a square-law response. Bipolar and field-effect transistors (FETs) can also be biased to give a square-law response.

4-1: Basic Principles of Amplitude Modulation

AM in the Frequency Domain

- Diodes and transistors whose function is not a pure square-law function produce third-, fourth-, and higher-order harmonics, which are sometimes referred to as **intermodulation products**.
- Intermodulation products are easy to filter out.
- Tuned circuits filter out the modulating signal and carrier harmonics, leaving only carrier and sidebands.

4-1: Basic Principles of Amplitude Modulation

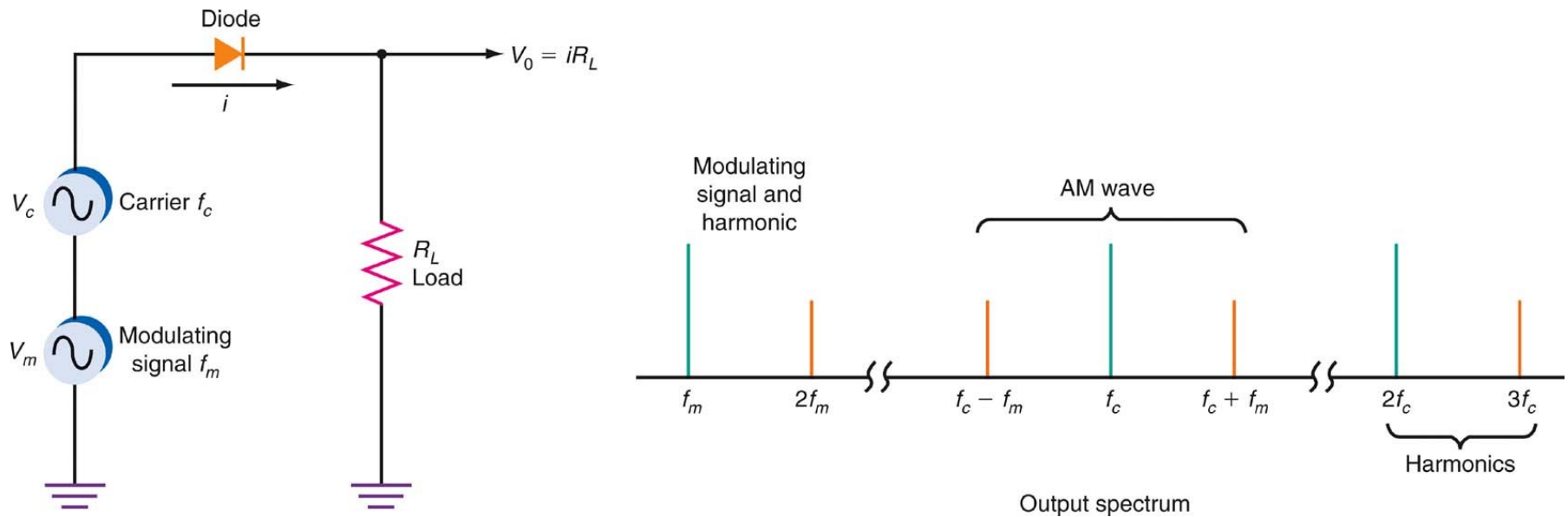


Figure 4-4 A square-law circuit for producing AM.

4-1: Basic Principles of Amplitude Modulation

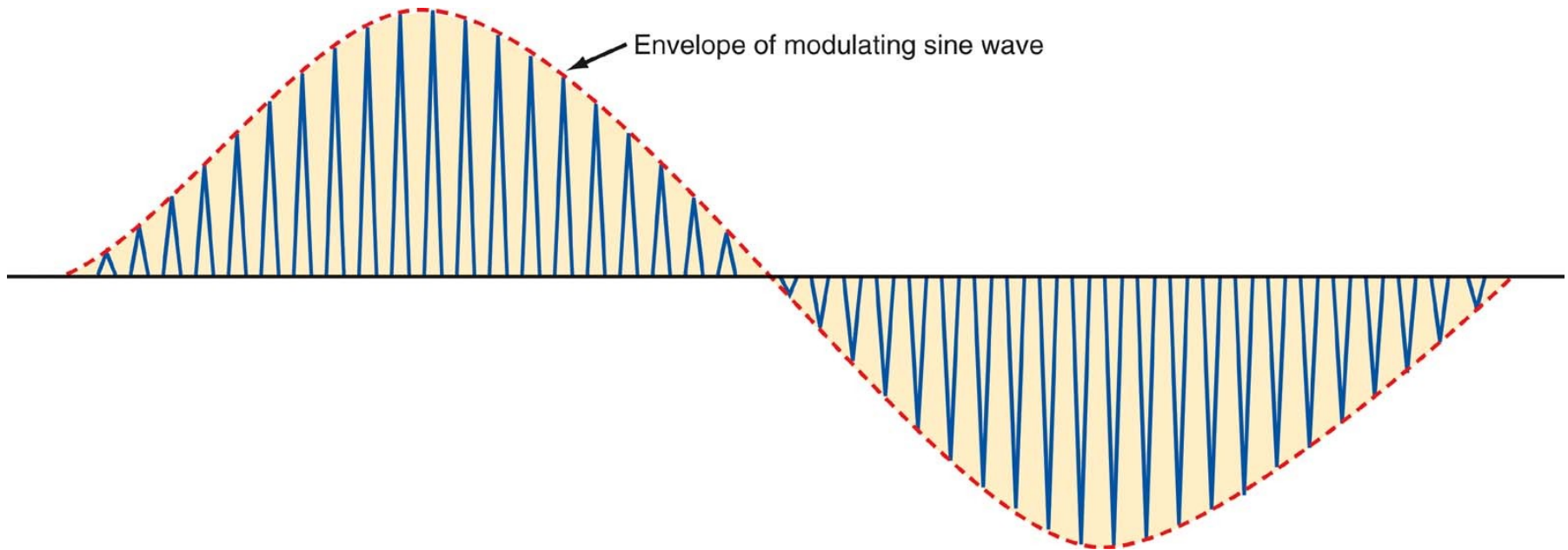


Figure 4-5 AM signal containing not only the carrier and sidebands but also the modulating signal.

4-1: Basic Principles of Amplitude Modulation

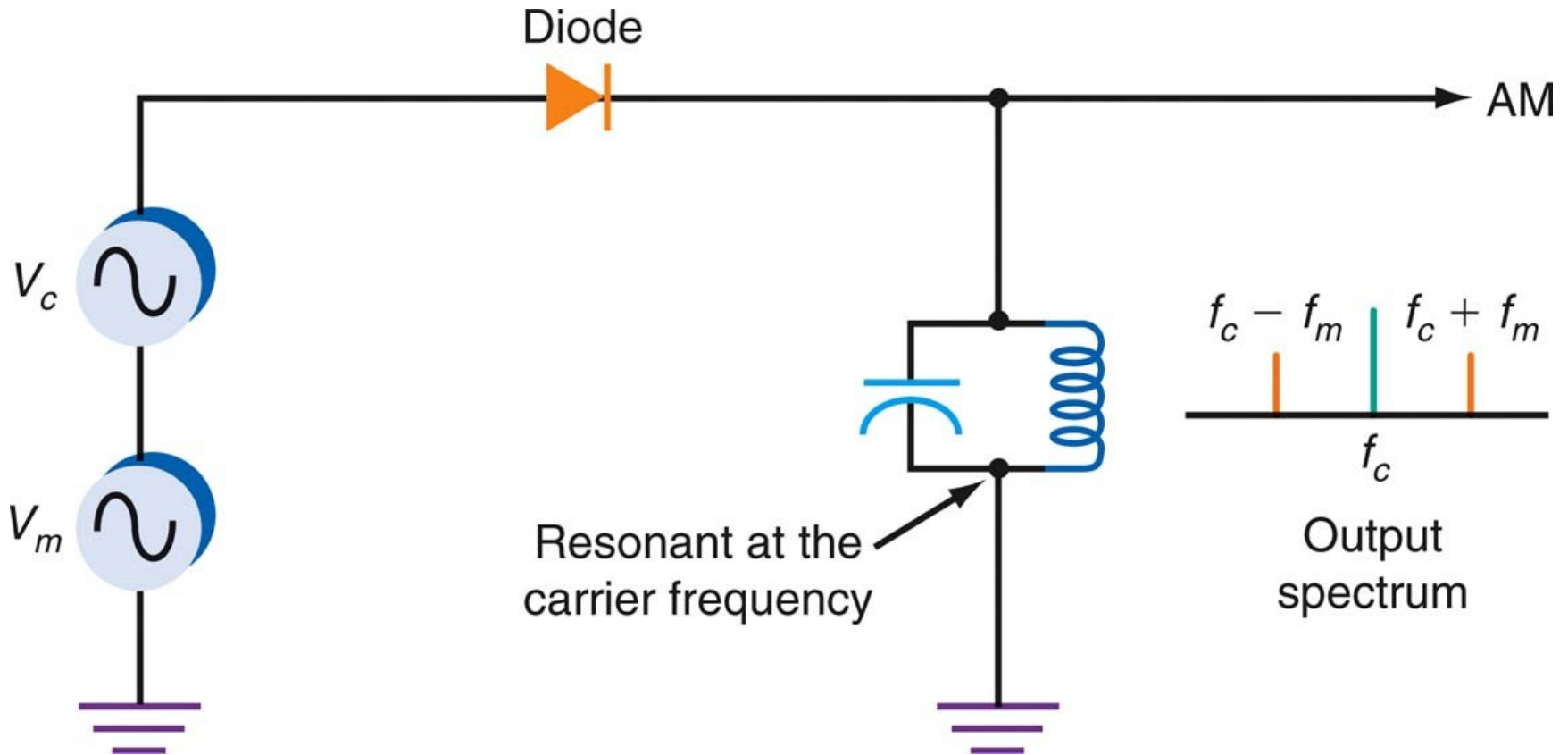


Figure 4-6 The tuned circuit filters out the modulating signal and carrier harmonics, leaving only the carrier and sidebands.

4-2: Amplitude Modulators

- There are two types of amplitude modulators. They are **low-level** and **high-level modulators**.
- Low-level modulators generate AM with small signals and must be amplified before transmission.
- High-level modulators produce AM at high power levels, usually in the final amplifier stage of a transmitter.

4-2: Amplitude Modulators

Low-Level AM: Diode Modulator

- **Diode modulation** consists of a resistive mixing network, a diode rectifier, and an *LC* tuned circuit.
- The carrier is applied to one input resistor and the modulating signal to another input resistor.
- This resistive network causes the two signals to be linearly mixed (i.e. algebraically added).
- A diode passes half cycles when forward biased.
- The coil and capacitor repeatedly exchange energy, causing an oscillation or ringing at the resonant frequency.

DIODE MODULATOR

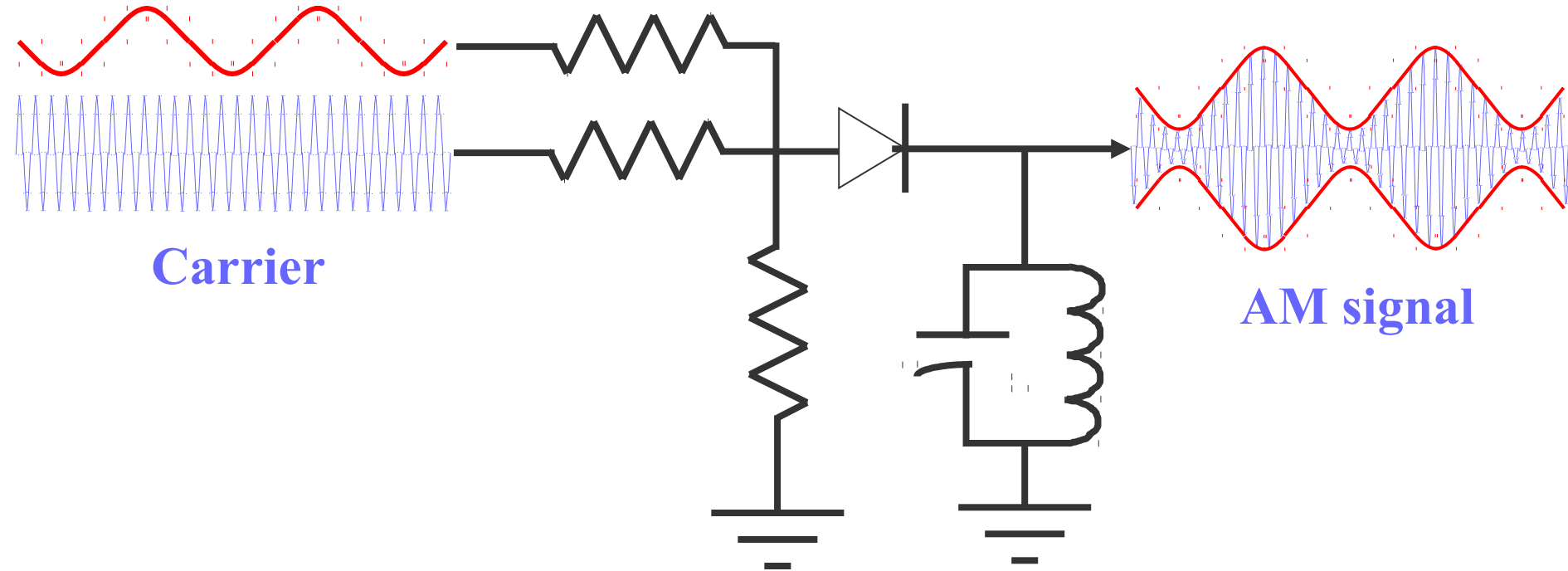
Information

**Diode provides
multiplication**

**Envelope matches
information signal**

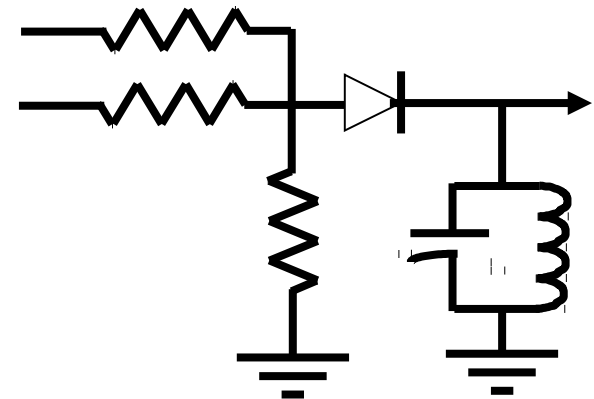
Carrier

AM signal



HOW THE DIODE MODULATOR WORKS

- The resistive network adds the carrier and modulating signals.
- The diode rectifies the result producing non-linear mixing.
- The parallel tuned circuit selects the carrier and sidebands and rejects the modulating signal.



4-2: Amplitude Modulators

Low-Level AM: Transistor Modulator

- **Transistor modulation** consists of a resistive mixing network, a transistor, and an LC tuned circuit.
- The emitter-base junction of the transistor serves as a diode and nonlinear device.
- Modulation and amplification occur as base current controls a larger collector current.
- The LC tuned circuit oscillates (rings) to generate the missing half cycle.

4-2: Amplitude Modulators

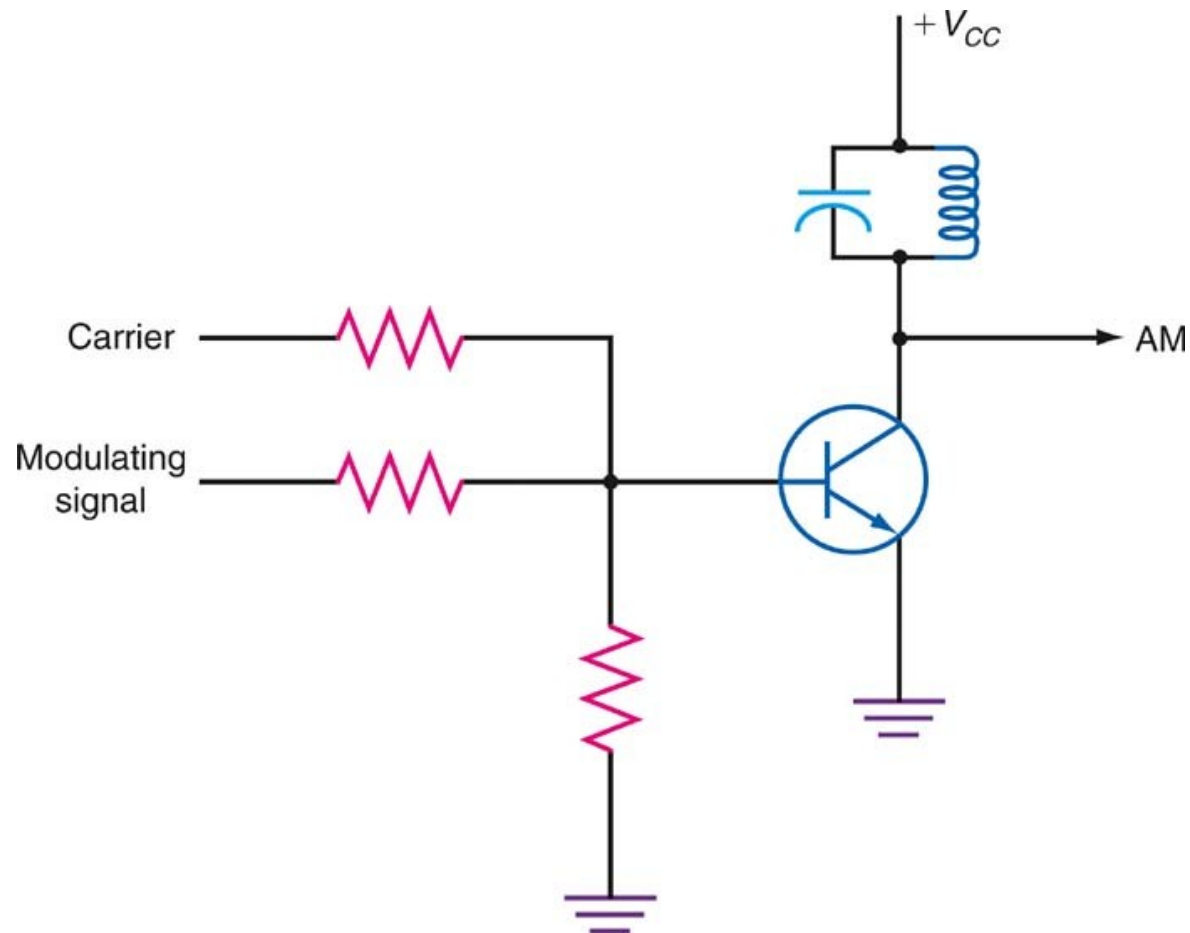


Figure 4-9 Simple transistor modulator.

4-2: Amplitude Modulators

Low-Level AM: PIN Diode Modulator

- Variable attenuator circuits using **PIN diodes** produce AM at VHF, UHF, and microwave frequencies.
- PIN diodes are special type silicon junction diodes designed for use at frequencies above 100 MHz.
- When PIN diodes are forward-biased, they operate as variable resistors.
- Attenuation caused by PIN diode circuits varies with the amplitude of the modulating signal.

4-2: Amplitude Modulators

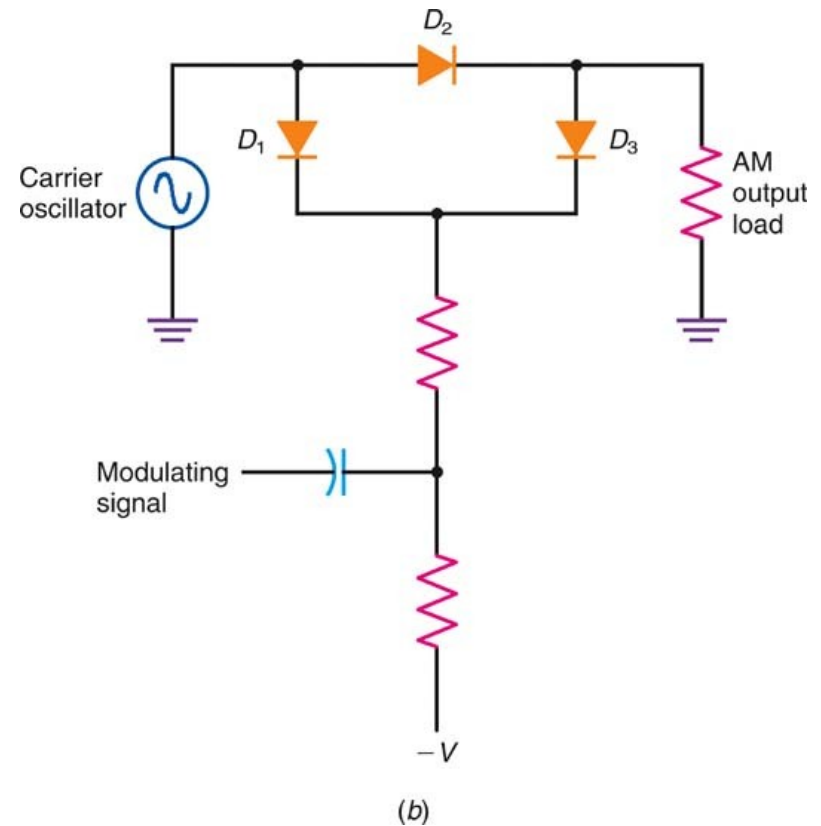
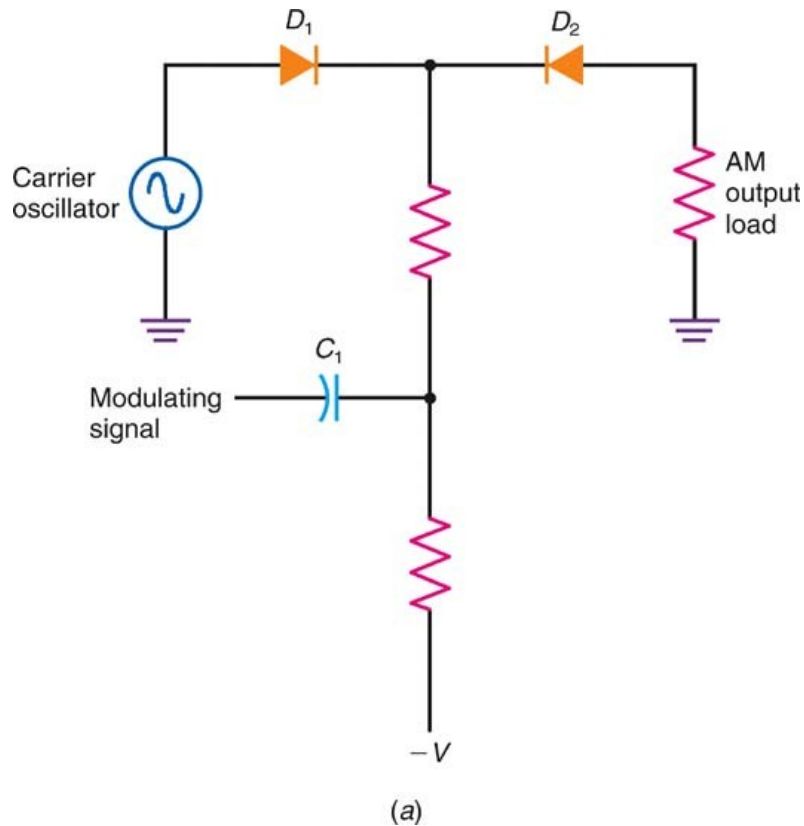


Figure 4-10 High-frequency amplitude modulators using PIN diodes.

4-2: Amplitude Modulators

Low-Level AM: PIN Diode Modulator

- 2 PIN diodes are connected back to back and are forward-biased by a fixed negative dc voltage.
- The modulating signal is applied to the diodes through the capacitor C1.
- This ac modulating signal rides on the dc bias, adding to and subtracting from it. Thus varying the resistance of the PIN diodes.
- These diodes appear in series with the carrier oscillator and the load.

4-2: Amplitude Modulators

Low-Level AM: PIN Diode Modulator

- A positive-going modulating signal reduces the bias on PIN diodes, causing their resistance to go up. This causes a reduction in amplitude of the carrier across the load.
- A negative-going modulating signal adds to the forward bias, causing the resistance of the diodes to go down, thereby increasing the carrier amplitude.
- Fig. 4-10(b) shows the variation of PIN diodes modulator circuit, arranged in a pi network.
- Used to maintain a constant circuit impedance even under modulation.

4-2: Amplitude Modulators

Low-Level AM: Differential Amplifier

- Differential amplifier modulators make excellent amplitude modulators because they have a high gain, good linearity and can be 100 percent modulated.
- The output voltage can be taken between two collectors, producing a **balanced**, or **differential**, output.
- The output can also be taken from the output of either collector to ground, producing a **single-ended output**.

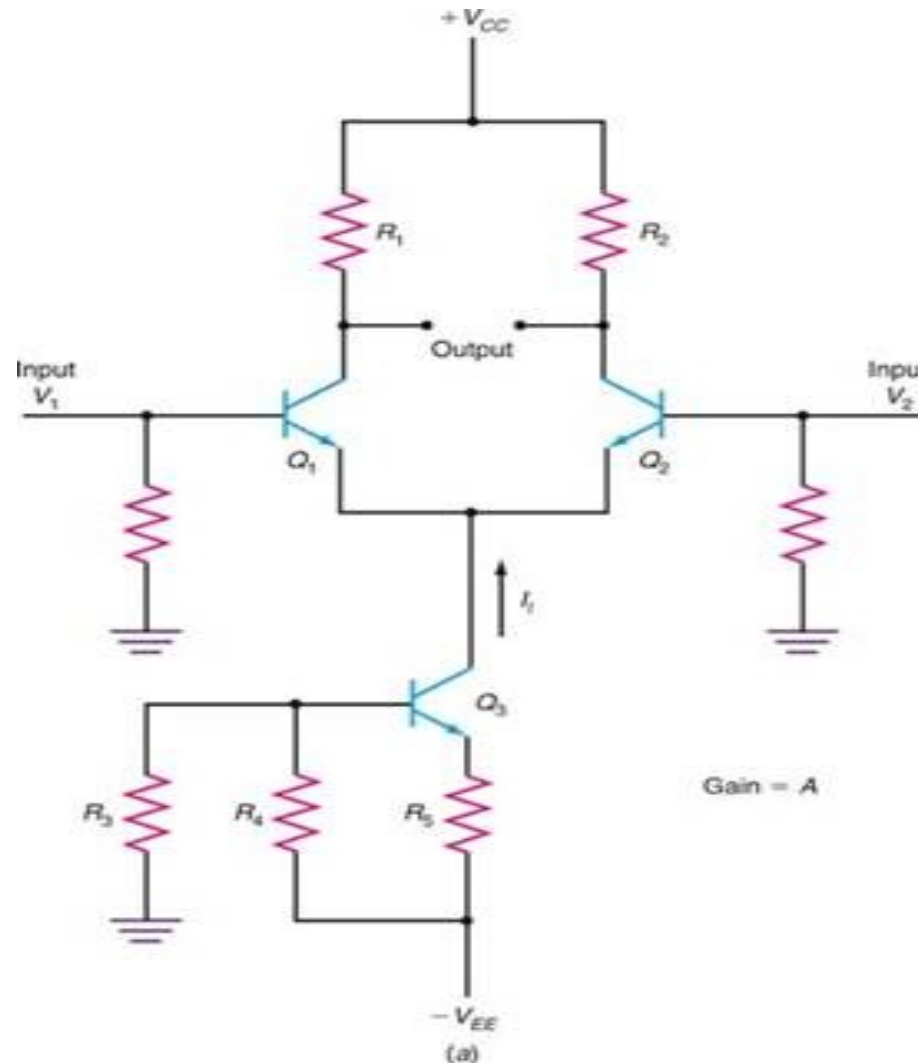
4-2: Amplitude Modulators

Low-Level AM: Differential Amplifier

- The modulating signal is applied to the base of a constant-current source transistor.
- The modulating signal varies the emitter current and therefore the gain of the circuit.
- The result is AM in the output.

4-2: Amplitude Modulators

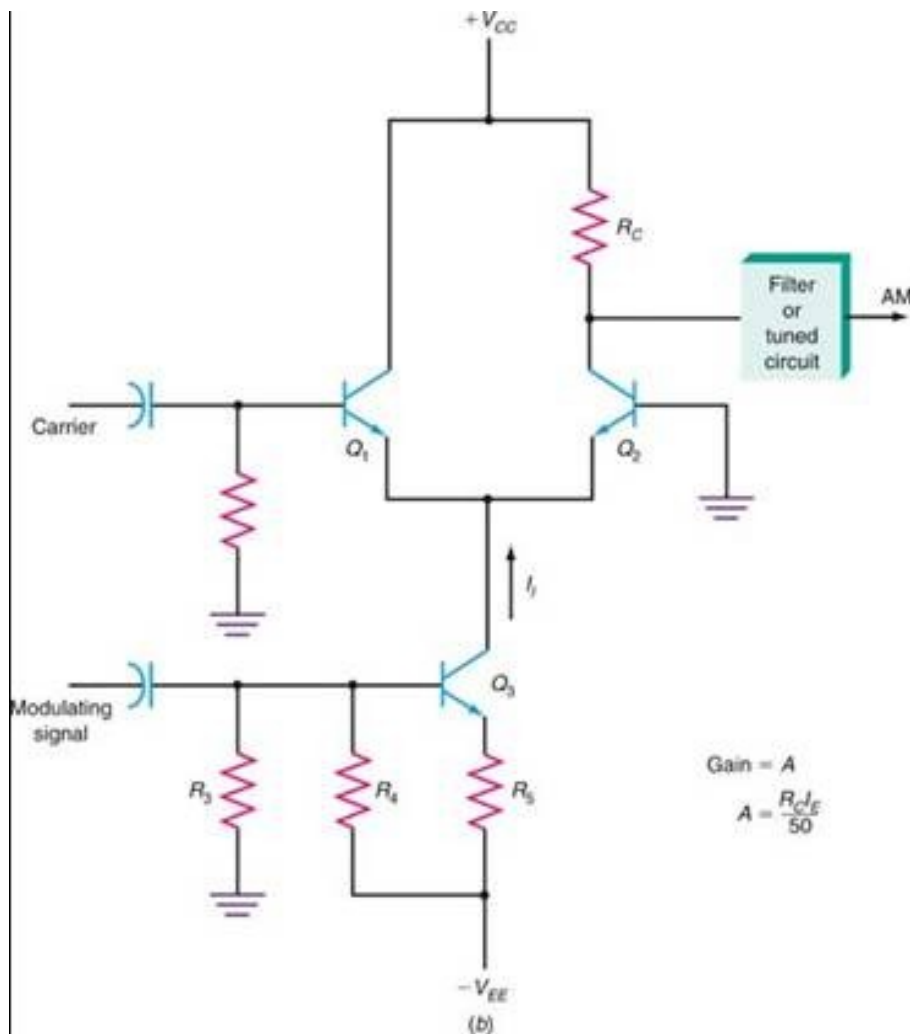
- Q1 and Q2 from the diff pair, Q3 is a constant current source.
- Q3 supplies a fixed emitter current I_E to Q1 and Q2; one-half of which flows in each transistor.
- The output is developed across the collector resistor R1 and R2.
- $V_{OUT} = A(V_2 - V_1)$; A is the circuit gain



4-2: Amplitude Modulators

- Differential amplifier can also be operate with the single input.
- When this is done, the other input is grounded or set to zero.
- If V_1 is zero, the output is $V_{OUT}=A(V_2)$.
- If V_2 is zero, the output is $V_{OUT}=A(-V_1)$. This means the circuits inverts V_1 .
- An approximation of the gain is given by the expression $A=R_{C|E}/50$. this is the single-ended gain, where the output is taken from one of the collector respected to ground.

4-2: Amplitude Modulators



- Carrier is applied to the base of Q_1 and base of Q_2 is grounded.
- The output taken from the collector of Q_2 , is single-ended.
- The modulating signal is applied to the base of the constant-current source Q_3 .
- As the intelligence signal varies, it varies the emitter current.

4-2: Amplitude Modulators

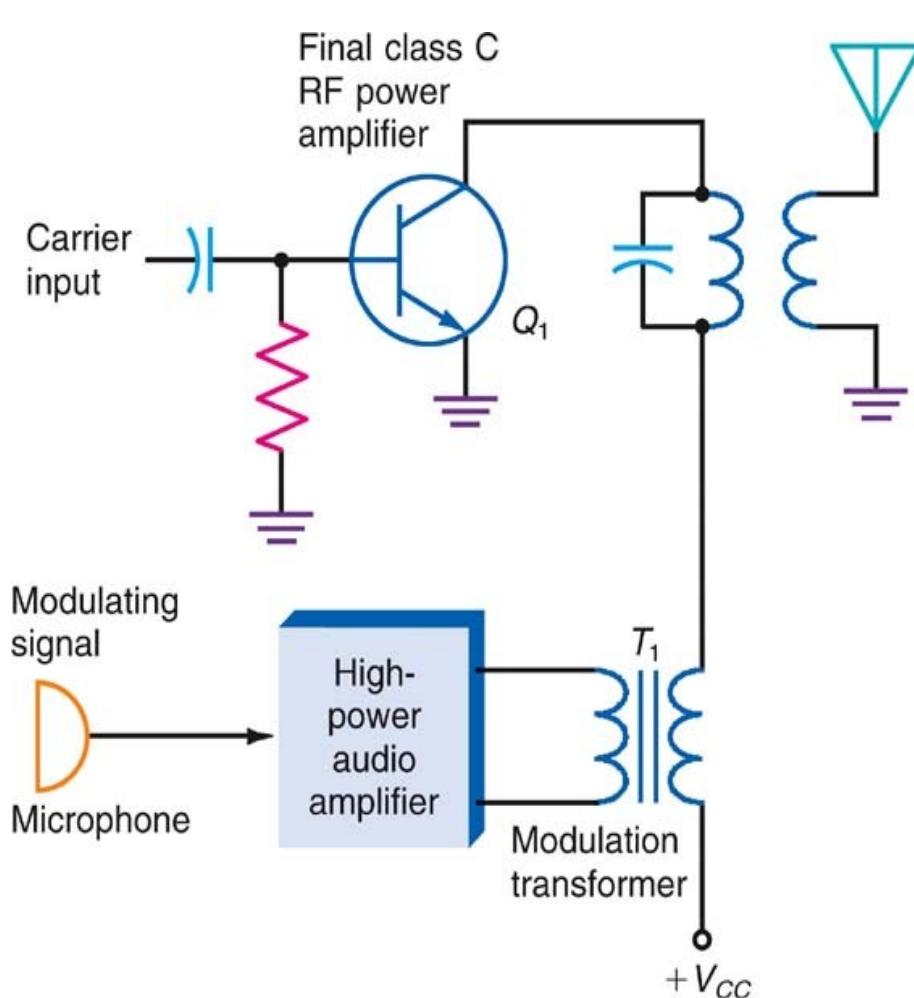
- This change the gain of the circuit, amplifying the carrier by an amount determined by the modulating signal amplitude.
- The results is AM in the output.
- The modulating signal can be removed by using a simple filter.

4-2: Amplitude Modulators

High-Level AM

- In **high-level modulation**, the modulator varies the voltage and power in the final RF amplifier stage of the transmitter.
- The result is high efficiency in the RF amplifier and overall high-quality performance.

4-2: Amplitude Modulators



High-Level AM: Collector Modulator

- The **collector modulator** is a linear power amplifier that takes the low-level modulating signals and amplifies them to a high-power level.
- A modulating output signal is coupled through a modulation transformer to a class C amplifier.
- The secondary winding of the modulation transformer is connected in series with the collector supply voltage of the class C amplifier.

4-2: Amplitude Modulators

- When zero-modulation input signal:
- There is zero-modulation voltage across the secondary of T1
- The collector supply voltage is applied directly to the class C amplifier, and the output carrier is a steady sine wave.

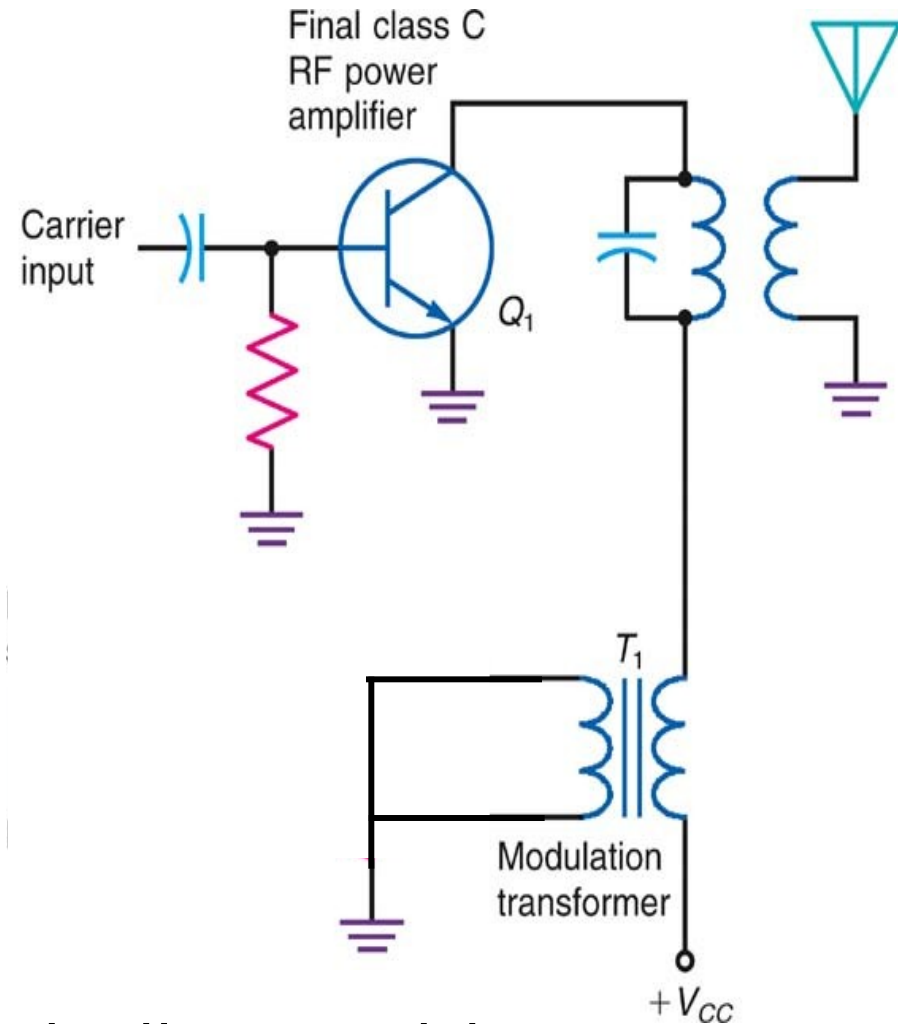


Figure 4-13 A high-level collector modulator.

4-2: Amplitude Modulators

- When the modulating input signal occurs:
- The AC voltage of the modulating signal across the secondary of the modulation transformer is added to and subtracted from the dc collector supply voltage.
- This varying supply voltage is then applied to class C amplifier, causing the amplitude of the current pulse through transistor Q1 to vary.
- The amplitude of the carrier sine wave in accordance with the modulated signal.

4-2: Amplitude Modulators

- When the modulation signal goes positive, it adds to the collector supply voltage.
- Thereby increasing its value and causing higher current pulses and a higher-amplitude carrier.
- When the modulation signal goes negative, it subtracts from the collector supply voltage, decreasing it.
- The class C amplifier current pulses are smaller, resulting in a low-amplitude carrier output.

4-2: Amplitude Modulators

- High-level modulation produces the best type of AM, but it requires an extremely high-power modulator circuit.
- In fact, for 100% modulation, the power supplied by the modulator must be equal to one-half the total class C amplifier input power.
- If the class C amplifier has an input power of 1000W, the modulator must be able to deliver one-half this amount, or 500W

4-2: Amplitude Modulators

High-Level AM: Series Modulator

- A **series modulator** produces high-level modulation without a large and expensive modulation transformer used in collector modulators.
- It improves frequency response.
- It is, however, very inefficient.

4-2: Amplitude Modulators

High-Level AM: Series Modulator

- A series modulator replaces the modulation transformer with an emitter follower.
- The modulating signal is applied to the emitter follower.
- The emitter follower is in series with the collector supply voltage.
- The collector voltage changes with variations in the amplified audio modulating signal.

4-2: Amplitude Modulators

High-Level AM: Series Modulator

- Very inefficient compared to modulating transformer.
- Collector supply voltage of 24V and collector current of 0.5A.
- If no modulating signal applied, $m=0$.
- The emitter follower biased so that the base and emitter are at a dc voltage of about one-half supply voltage (12V)
- The collector supply voltage on the class C amplifier is 12 and input power is 6W.

4-2: Amplitude Modulators

High-Level AM: Series Modulator

- At $m=100\%$, the collector voltage and current on Q1 must double.
- This will occur when the audio input is at +ve peak.
- At this time most of the audio signal appears at the emitter of Q1 and very little of the signal appears between the emitter and collector of Q2, and so at 100 % modulation, Q2 dissipates very little power.
- When the audio is at negative peak. The voltage at the emitter of Q2 is reduced to 12V, so another 12V appears between emitter and collector Q2.
- Efficiency drops to less than 50%.

4-2: Amplitude Modulators

High-Level AM: Series Modulator

- Modulation transformer can perform until up to 80%.
- This arrangement is not practical for very high power AM, but it does make an effective higher level modulator for power level about 100W

4-2: Amplitude Modulators

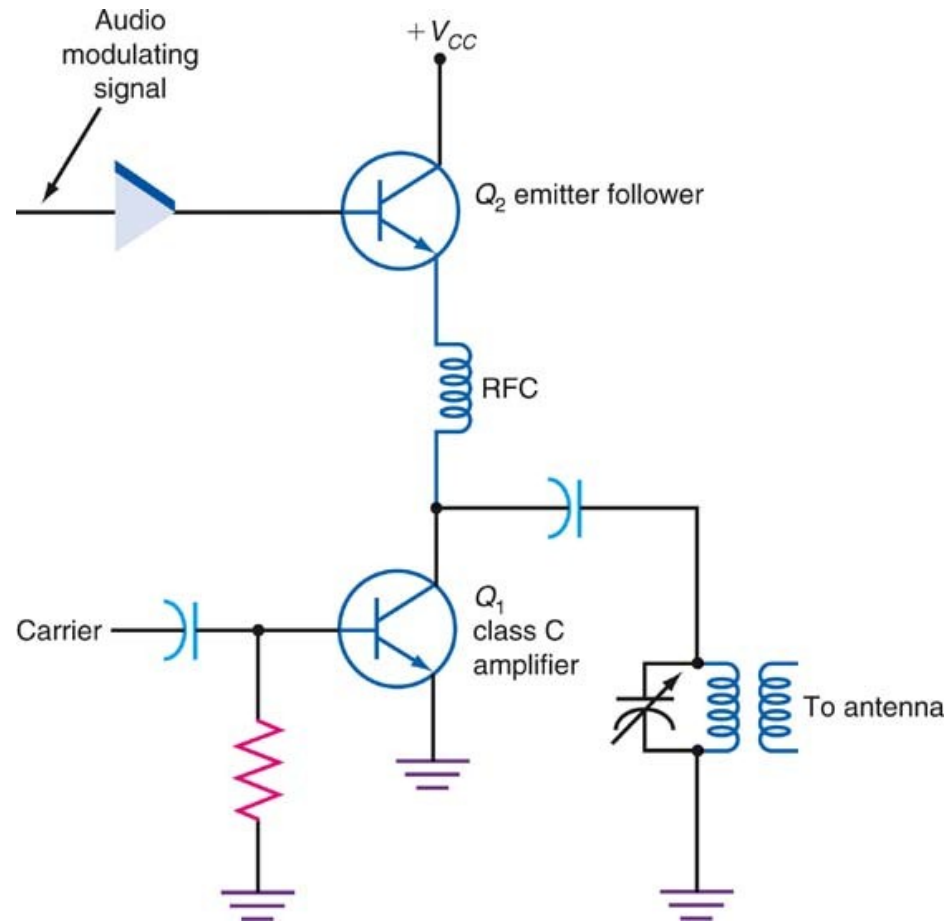


Figure 4-15 Series modulation. Transistors may also be MOSFETs with appropriate biasing.

4-3: Amplitude Demodulators

- **Demodulators**, or detectors, are circuits that accept modulated signals and recover the original modulating information.

4-3: Amplitude Demodulators

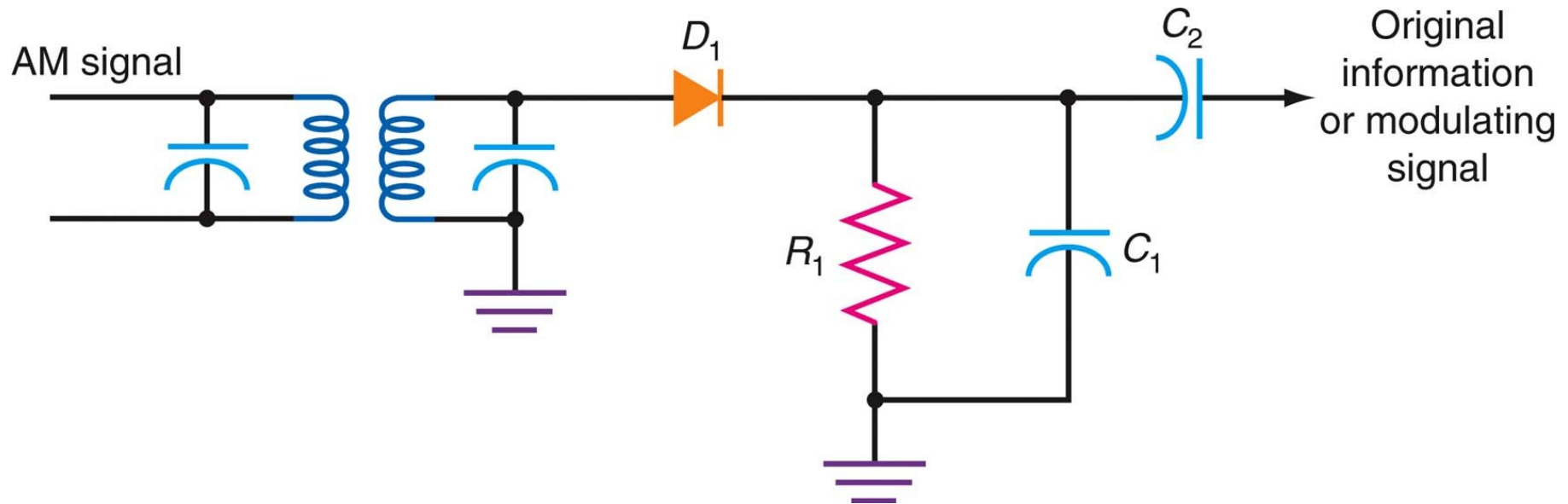


Figure 4-16 A diode detector AM demodulator.

4-3: Amplitude Demodulators

Diode Detector

- On positive alternations of the AM signal, the capacitor charges quickly to the peak value of pulses passed by the diode.
- When the pulse voltage drops to zero, the capacitor discharges into the resistor.
- The time constant of the capacitor and resistor is long compared to the period of the carrier.
- The capacitor discharges only slightly when the diode is not conducting.
- The resulting waveform across the capacitor is a close approximation to the original modulating signal.

4-3: Amplitude Demodulators

Diode Detector

- Because the diode detector recovers the envelope of the AM (modulating) signal, the circuit is sometimes called an **envelope detector**.
- If the RC time constant in a diode detector is too long, the capacitor discharge will be too slow to follow the faster changes in the modulating signal.
- This is referred to as **diagonal distortion**.

4-3: Amplitude Demodulators

Synchronous Detection

- **Synchronous detectors** use an internal clock signal at the carrier frequency in the receiver to switch the AM signal off and on, producing rectification similar to that in a standard diode detector.
- Synchronous detectors or **coherent detectors** have less distortion and a better signal-to-noise ratio than standard diode detectors.

4-3: Amplitude Demodulators

Synchronous Detection

- The key to making the synchronous detector work is to ensure that the signal producing the switching action is perfectly in phase with the received AM carrier.
- An internally generated carrier signal from an oscillator will not work.

4-3: Amplitude Demodulators

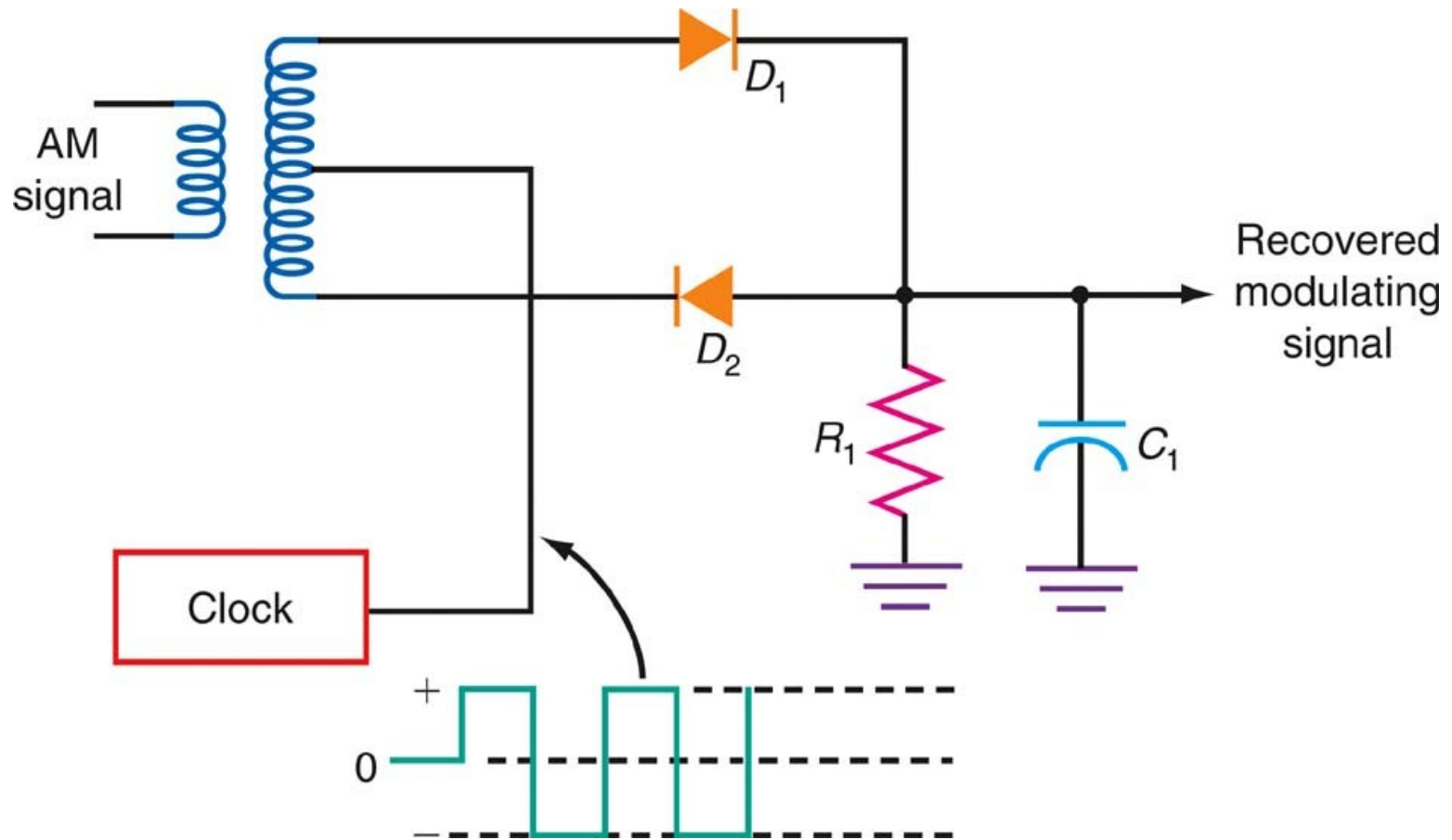


Figure 4-22 A practical synchronous detector.

4-4: Balanced Modulator

- A **balanced modulator** is a circuit that generates a DSB signal, suppressing the carrier and leaving only the sum and difference frequencies at the output.
- The output of a balanced modulator can be further processed by filters or phase-shifting circuitry to eliminate one of the sidebands, resulting in a SSB signal.
- Types of balanced modulators include lattice, 1496/1596 IC, and the analog multiplier.

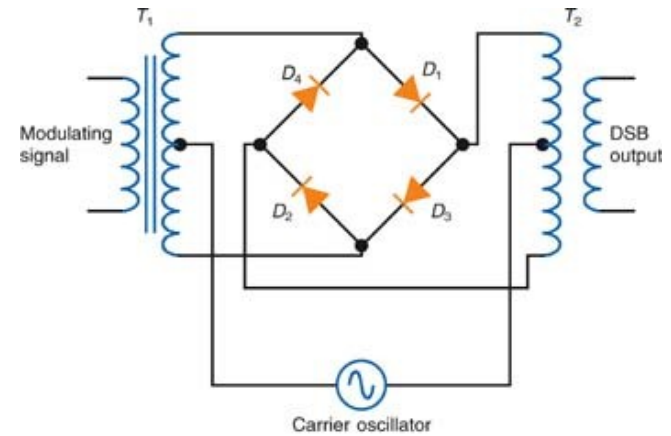
4-4: Balanced Modulator

Lattice Modulator

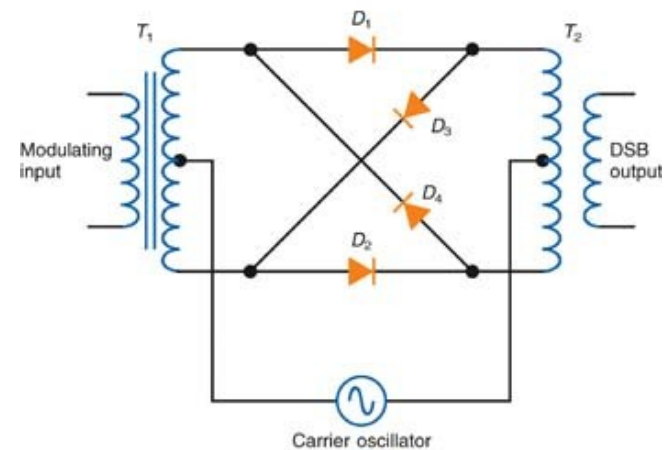
- A popular and widely used balanced modulator is the diode ring or **lattice modulator**.
- The lattice modulator consists of an input transformer, an output transformer and four diodes connected in a bridge circuit.
- The carrier signal is applied to the center taps of the input and output transformers.
- The modulating signal is applied to the input transformer.
- The output appears across the output transformer.

4-4: Balanced Modulator

Figure 4-24: Lattice-type balanced modulator.



(a)



(b)

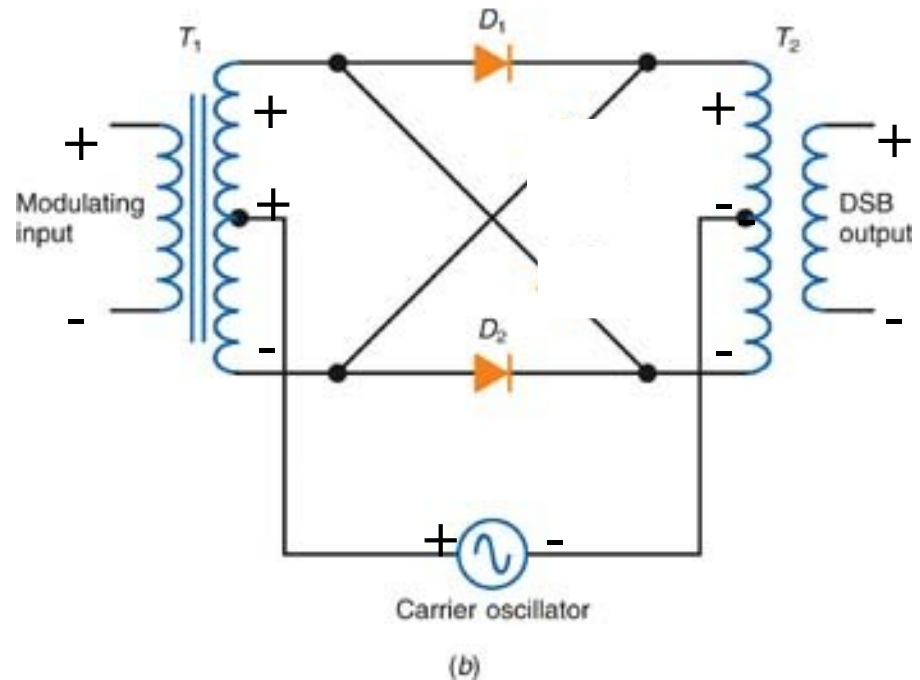
4-4: Balanced Modulator

Lattice Modulators

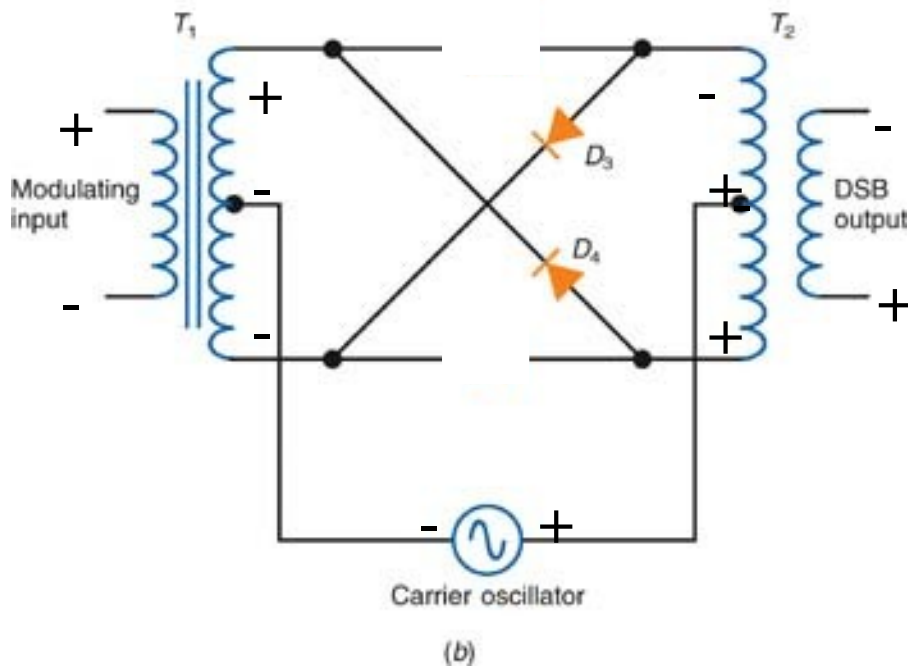
- The carrier sine wave is considerably higher in frequency and amplitude than the modulating signal.
- The carrier sine wave is used as a source of forward and reverse bias for the diodes.
- The carrier turns the diodes off and on at a high rate of speed.
- The diodes act like switches that connect the modulating signal at the secondary of T_1 to the primary of T_2 .

4-4: Balanced Modulator

- Low frequency sine wave is applied to the primary of T_1 , so the modulating signal appears across the secondary of T_1 .
- When the carrier polarity is positive, D_1 and D_2 conduct and act as closed switches.
- D_3 and D_4 are reverse biased and act as open switches.



4-4: Balanced Modulator



- When the carrier polarity reverses, D_1 and D_2 cut off and D_3 and D_4 conduct.
- Modulating signal at the secondary of T_1 is applied to the primary of T_2 , but this time the leads have been effectively reversed because of the connection of D_3 and D_4 .
- The result is a 180 deg phase reversal.

4-4: Balanced Modulator

IC Balanced Modulators

- The 1496/1596 IC is a versatile circuit available for communication applications.
- It can work at carrier frequencies up to 100 MHz.
- It can achieve a carrier suppression of 50 to 65 dB.
- The 1496/1596 IC can operate as a balanced modulator or configured to perform as an amplitude modulator, a product detector, or a synchronous detector.

4-4: Balanced Modulator

IC Balanced Modulators: Analog Multiplier

- An **analog multiplier** is a type of integrated circuit that can be used as a balanced modulator.
- Analog multipliers are often used to generate DSB signals.
- The analog multiplier is not a switching circuit like the balanced modulator.
- The analog multiplier uses differential amplifiers operating in the linear mode.
- The carrier must be a sine wave and the multiplier produces the true product of two analog inputs.

4-5: SSB Circuits

Generating SSB Signals: The Filter Method

- The **filter method** is the simplest and most widely used method of generating SSB signals.
- The modulating signal is applied to the audio amplifier.
- The amplifier's output is fed to one input of a balanced modulator.
- A crystal oscillator provides the carrier signal which is also applied to the balanced modulator.

4-5: SSB Circuits

Generating SSB Signals: The Filter Method

- The output of the balanced modulator is a double-sideband (DSB) signal.
- An SSB signal is produced by passing the DSB signal through a highly selective bandpass filter.
- With the filter method, it is necessary to select either the upper or the lower sideband.

4-5: SSB Circuits

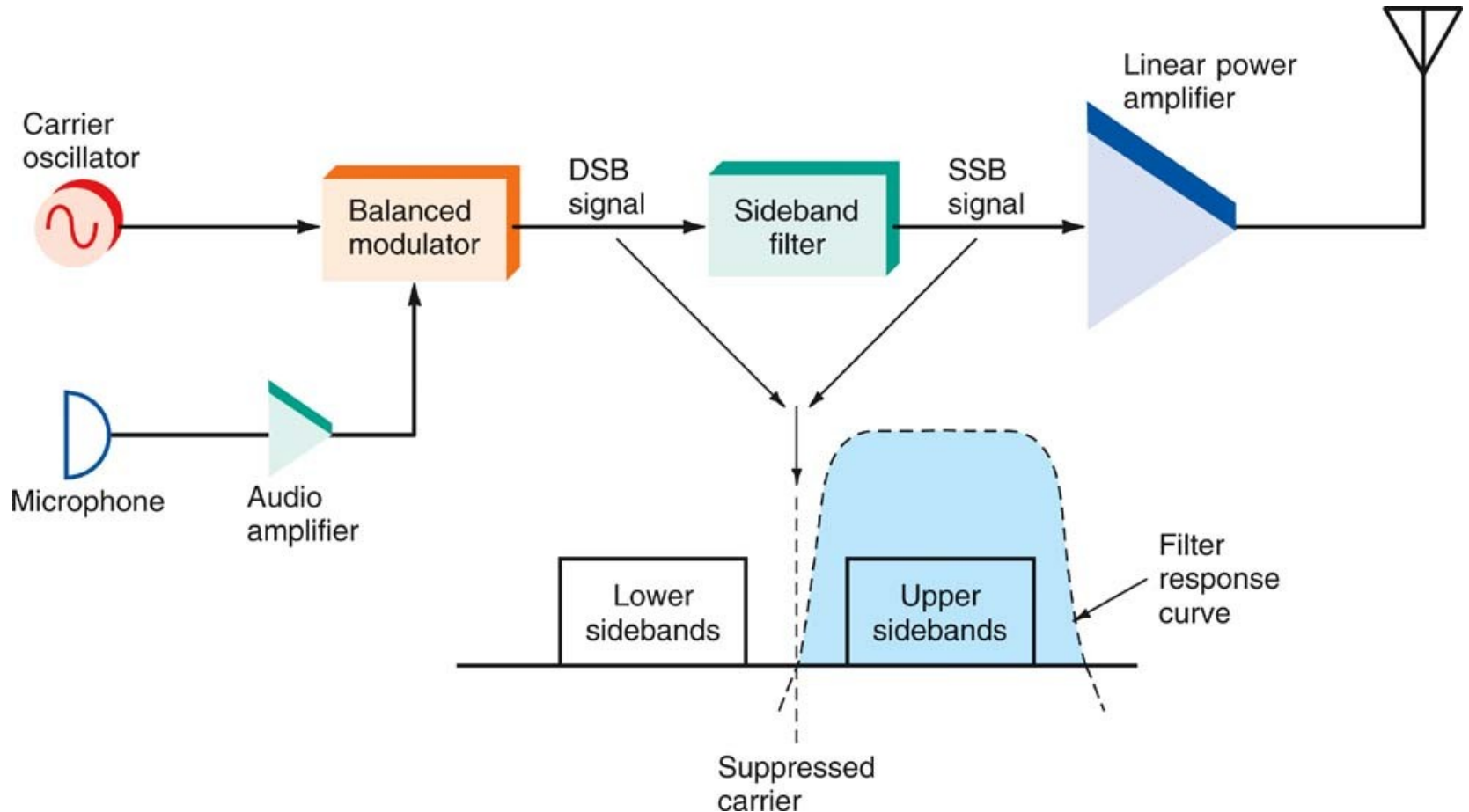


Figure 4-31 An SSB transmitter using the filter method.

4-5: SSB Circuits

Generating SSB Signals: Phasing Method

- The **phasing method** of SSB generation uses a phase-shift technique that causes one of the sidebands to be canceled out.
- The phasing method uses two balanced modulators which eliminate the carrier.
- The carrier oscillator is applied to the upper balanced modulator along with the modulating signal.

4-5: SSB Circuits

Generating SSB Signals: Phasing Method

- The carrier and modulating signals are both shifted in phase by 90 degrees and applied to another balanced modulator.
- Phase-shifting causes one sideband to be canceled out when the two modulator outputs are added together.

4-5: SSB Circuits

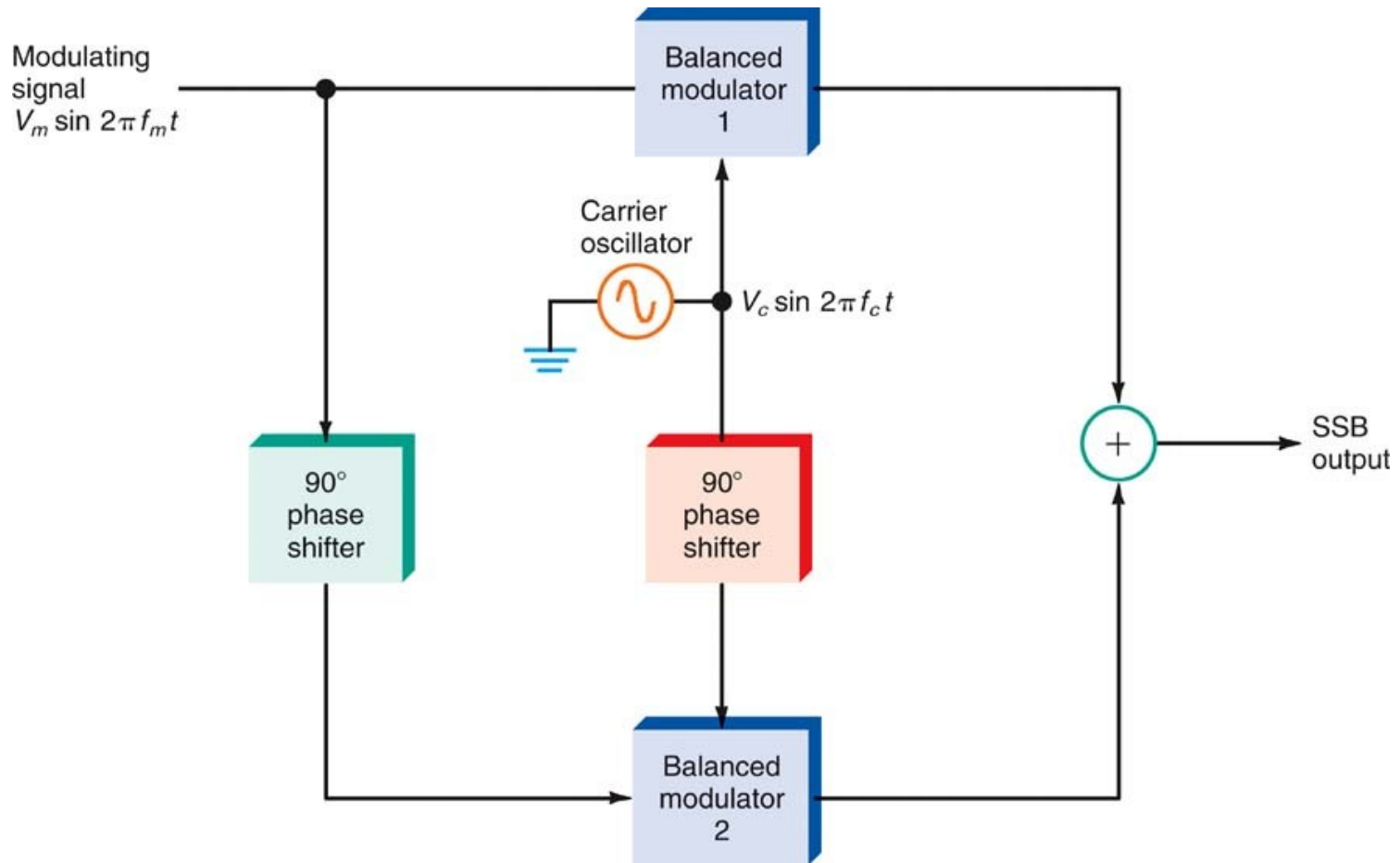


Figure 4-33 An SSB generator using the phasing method.

4-5: SSB Circuits

DSB and SSB Demodulation

- To recover the intelligence in a DSB or SSB signal, the carrier that was suppressed at the receiver must be reinserted.
- A **product detector** is a balanced modulator used in a receiver to recover the modulating signal.
- Any balanced modulator can be used as a product detector to demodulate SSB signals.

4-5: SSB Circuits

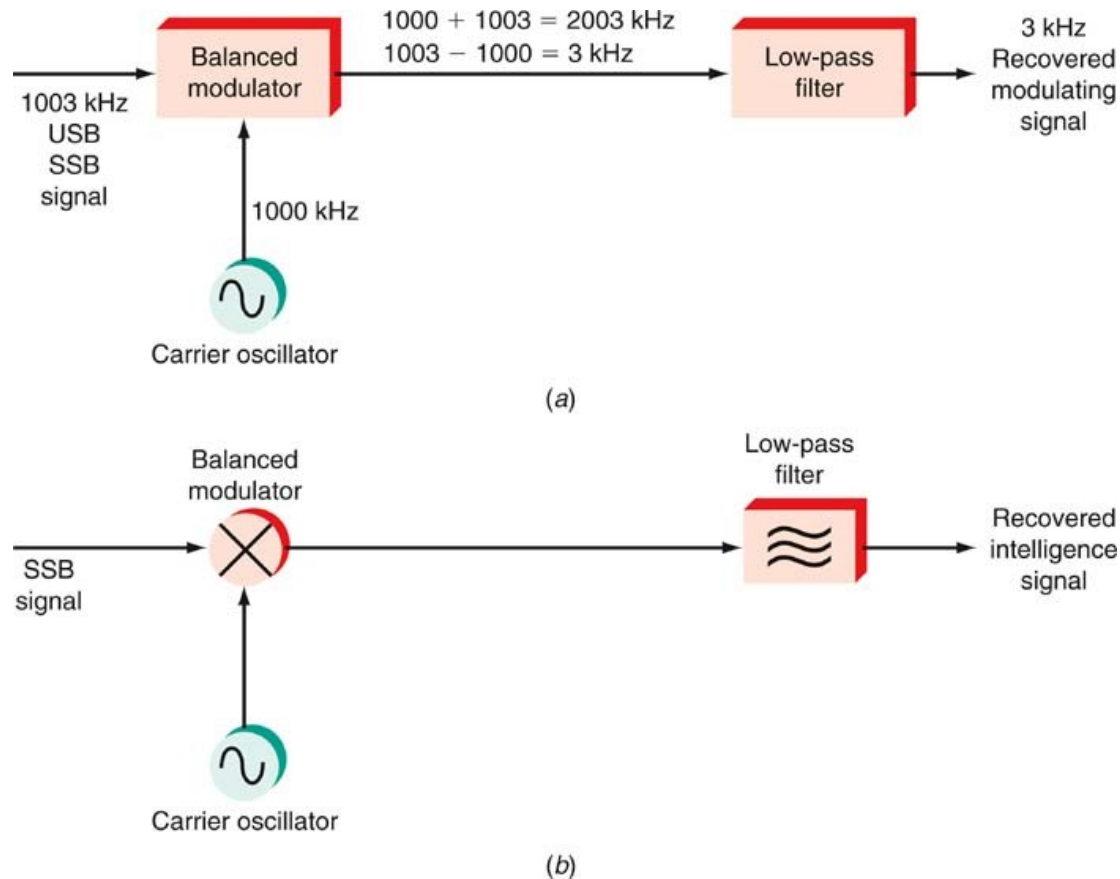


Figure 4-38 A balanced modulator used as a product detector to demodulate an SSB signal.

At this stage you should be able to:

- Explain the relationship of the basic equation for an Am signal to production of amplitude modulation, mixing and frequency conversion by a diode or other nonlinear frequency component or circuit.
- Describe the operation of diode modulator circuits and diode detector circuits.
- Compare the advantages and disadvantages of low and high level modulation.
- Explain how the performance of a basic diode detector is enhanced by using full-wave rectifier circuit.

At this stage you should be able to:

- Define synchronous detection and explain the role of clippers in synchronous detector circuits.
- ***State the function of balanced modulators and describe the differences between lattice and IC modulator circuits.***